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Seeing Pedestrians at Night: Visual Clutter Does Not Mask Biological Motion

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Abstract

Although placing reflective markers on pedestrians' major joints can make pedestrians more conspicuous to drivers at night, it has been suggested that this "biological motion" effect may be reduced when visual clutter is present. We tested whether extraneous points of light affected the ability of 12 younger and 12 older drivers to see pedestrians as they drove on a closed road at night. Pedestrians wore black clothing alone or with retroreflective markings in four different configurations. One pedestrian walked in place and was surrounded by clutter on half of the trials. Another was always surrounded by visual clutter but either walked in place or stood still. Clothing configuration, pedestrian motion, and driver age influenced conspicuity but clutter did not. The results confirm that even in the presence of visual clutter pedestrians wearing biological motion configurations are recognized more often and at greater distances than when they wear a reflective vest.

KEYWORDS:

Pedestrian; Visibility; Conspicuity; Night driving

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1. Introduction

Collisions between vehicles and pedestrians represent a significant problem. In the US, for example, around 60,000 pedestrians are injured and approximately 5000 pedestrians are killed each year (accounting for roughly 11% of all US traffic fatalities; NHTSA, 2008). But the problem is even worse elsewhere. For example, Rumar (2001) reported that 42% of all traffic fatalities in Asia are pedestrians. Rumar also reported that, globally, 200,000 pedestrians are killed at night each year. In their analysis of five major transportation safety issues facing the US, Sivak, et al. (2007) cited enhancing the safety of night driving – particularly reducing nighttime crashes involving pedestrians – as a “major opportunity” to advance road safety. While crashes are typically complex events with a mix of causal factors, it is clear that crashes between vehicles and pedestrians are overrepresented at night and there is strong evidence that visibility issues are a key factor. Analyses of crash databases have determined, for example, that the increased incidence of crashes involving pedestrians at night is primarily a consequence of lower illumination rather than other factors that vary between day and night such as driver fatigue and the use of alcohol (Owens & Sivak 1996; Sullivan & Flannagan 2002). This suggests that at night drivers are often unable to recognize and respond to pedestrians from a safe distance (Rumar, 1990). Considerable behavioral evidence supports this hypothesis (see Kwan & Mapstone, 2006). Wood, Tyrrell, and Carberry (2005), for example, reported that only 5% of their drivers detected a roadside pedestrian wearing dark clothing when in a challenging but common nighttime condition (using low beams and facing an opposing vehicle’s headlights) even though the drivers were aware that experimenters were monitoring their ability to respond to pedestrians. While a variety of approaches have been used to make pedestrians more conspicuous to drivers at night (including evolving vehicle and roadway lighting technologies and night vision enhancement systems), an alternative approach is to have pedestrians wear clothing designs that take advantage of drivers' perceptual capacity to recognize the unique patterns of motion that specify normal human gait – biological motion (or biomotion).

Gunnar Johansson (1973, 1975) was the first to explore visual sensitivity to biological motion. Johansson showed observers films of actors making natural movements while wearing points of light on their major joints (ankles, knees, waist, shoulders, elbows, wrists). Although only these points of light were visible in Johansson's films, observers could recognize a walking human form in as little as 100-200 ms. Later research by Johansson and others confirmed that patterns of human motion are rich sources of information to which the human visual system is particularly attuned. Based only on the motion information available in point-light displays, observers can quickly recognize an actor's gender and emotion as well as the identity of their friends and the weight of unseen objects that are lifted by the actor (e.g., Cutting & Kozlowski, 1977; Pollick, et al., 2002; Runeson & Frykolm, 1981, 1983; see Blake & Shiffrar, 2007, for a review of the biomotion literature). Researchers have begun to identify the neural mechanisms involved in the perception of biomotion (e.g., Grossman, et al., 2000; Grossman, Battelli, & Pascual-Leone, 2005). Meanwhile, there has also been interest in capitalizing on our perceptual sensitivity to biomotion to enhance drivers' ability to see pedestrians from a safe distance at night.

While retroreflective materials (which are engineered to reflect light back in the direction of its source) have long been used to add visual contrast to pedestrians, these materials are most often attached to the pedestrian's torso. Reflective vests may not solve the conspicuity problem, however, since the torso exhibits relatively little motion during normal gait and because vests do not highlight the static human form. Indeed, numerous studies have reported that shifting retroreflectors from the torso to the extremities substantially enhances pedestrian conspicuity at night (Balk, Tyrrell, Brooks, & Carpenter, 2008; Blomberg, et al., 1986; Luoma & Penttinen, 1998; Luoma, et al., 1996; Owens, et al., 1994; Owens, et al., 2007; Sayer & Mefford, 2004; Wood, et al., 2005). In the study by Wood, et al. (2005), for example, drivers using low beams on a closed road recognized a pedestrian walking while wearing biomotion markers at a distance that was 3.4 times greater than when the pedestrian wore a vest that included an equal amount of retroreflective material. The finding that biomotion configurations can enhance pedestrian conspicuity is particularly appealing due to the low cost and ease of implementation by motivated individuals. The approach requires no upgrades to roadways or vehicles, the pedestrian is not required to carry a power source, and an approaching driver is not required to interpret an in-vehicle display.

To our knowledge, only one published report has failed to find a conspicuity advantage for pedestrians wearing biomotion configurations (Moberly & Langham, 2002). In that laboratory-based study, 65 participants viewed a 10-minute videotaped scenario of a nighttime drive and pressed a button when they were certain that a pedestrian was present. The authors found no support for their predictions that moving pedestrians would be seen at greater distances when retroreflective markings were attached to the pedestrian's ankles, knees, wrists, and elbows relative to when the pedestrian wore a reflective vest. The authors pointed to the presence of "high visual clutter" surrounding their pedestrian as a possible explanation for the negative finding. Because most relevant studies have been conducted in scenarios relatively free of visual clutter, it is possible that the presence of extraneous points of light surrounding a pedestrian – as is common in nighttime road environments – may mask the drivers' ability to perceive the biomotion markings as representing a pedestrian. Accordingly, the present study was designed to measure drivers' ability to recognize the presence of a roadside pedestrian at night both with and without the presence of visual clutter surrounding the pedestrian. Participants drove an instrumented vehicle on a closed road. Five different clothing configurations were tested, and both younger and older drivers were included.

2. Method

2.1 Participants

Twelve younger (21-34 years, mean = 26.3 years) and twelve older (61-78 years, mean = 70.3 years) volunteers participated. These participants were graduate students, friends of graduate students, and members of the participant database from the QUT School of Optometry. All participants were licensed drivers and had binocular visual acuity of 6/7.5 (20/25) or better. Participants wore the optical correction that they normally wear while driving, if any.

A questionnaire was administered to obtain an overall sense of the participants' driving habits and their perceptions of night driving. The younger and older participants reported having a mean of 10.8 years (std. dev.: 8.9 years) and 49.8 years (std. dev.: 7.9 years) of driving experience, respectively, $t(22) = 11.8$, $p < .001$. The younger and older drivers' mean estimate of the percentage of their driving in the past year that was on urban roads was 62% (std. dev.: 26%) and 42% (std. dev. 31%), respectively, $t(21) = 1.86$, $p = .08$. The younger and older drivers' also estimated that 12% (std. dev.: 12%) and 44.0% (std. dev.: 28%) had been on suburban or country roads, respectively, $t(14) = 3.75$, $p = .002$. The younger drivers estimated that during the previous year 40% (std. dev.: 22%) of their driving had been at night, while the older drivers estimated that only 16% (std. dev.: 11%) of their driving during the previous year had been at night, $t(18) = 3.75$, $p = .001$. On a 5-point scale from *very comfortable* to *very uncomfortable*, the older drivers rated nighttime driving in good weather as less comfortable than did their younger counterparts, $t(21) = 3.36$, $p = .003$. Despite this, on a 3-point scale from *never avoid* to *always avoid*, the older drivers did not report avoiding nighttime driving any more than the younger drivers, even when the night driving included heavy traffic, rain, or fog (all $p > .05$).

2.2 Closed-Road and Clutter

The experiment was conducted under nighttime conditions on the closed road circuit at the Mount Cotton Driver Training Centre, which has been used in previous studies of driving and vision (e.g., Wood, et al., 2005). Data were only collected when there was no active precipitation and when road surfaces were dry, and data collection began at least 60 minutes after sunset. The circuit, which is representative of a rural road, consists of a 2-3 lane asphalt road surface that includes hills, curves, bends, straight sections, and intersections as well as standard road signs and road markings. A 1.8 km (1.1 mile) section of the circuit was used for this study. The circuit has no street lighting. “Clutter zones” were established in the oncoming (right) lane at three points along the route (see Figure 1). Each clutter zone filled 26 m of the oncoming lane and consisted of a pre-configured array of eight elements that included varying amounts of retroreflective material. These elements consisted of three 110 cm-high posts, three small (35 cm high) traffic cones and two large (75 cm high) traffic cones. The total surface area of the retroreflective material mounted on the clutter elements was 7350 cm^2, roughly half of which faced the approaching vehicle and was illuminated by the vehicle’s headlamps.

Although the three clutter zones were configured similarly, from the driver’s perspective they appeared different due to variations in roadway curvature at the three sites. Clutter zone 1 was at the start of a tight leftward curve that immediately followed a rightward curve. Pedestrian

1 was positioned within this clutter zone facing the oncoming test vehicle. Clutter zone 2 was on a straight section of roadway that immediately followed a leftward curve. No pedestrians were positioned here. The third clutter zone was near the end of a long straight section of roadway; Pedestrian 2 was positioned on the far shoulder within this clutter zone, facing the oncoming test vehicle. The maximum distance at which the pedestrians could be seen in daylight (i.e., sight distance) was 87 m for Pedestrian 1 and 413 m for Pedestrian 2.

2.3 Pedestrian Clothing

The clothing of the two test pedestrians varied across laps. Five different clothing conditions were used: Black, Vest, Ankles, Ankles and Wrists (A+W), and Full Biomotion. In the Black condition the pedestrian wore all black clothing (black shoe covers, sweatpants, sweatshirt, and gloves). In the remaining four conditions the pedestrian wore the same black clothing but also wore 662.5 cm^2 of beaded retroreflective material (3M Scotchlite 8910 silver fabric) facing the approaching vehicle in different configurations. In the Vest condition the pedestrian wore a custom-made retroreflective rectangle on his chest, while in the Ankles condition the pedestrians wore a retroreflective strap on each ankle. In the A+W condition the retroreflective material was distributed equally across the ankles and wrists. The Full Biomotion configuration included retroreflective markings on the ankles, knees, waist, shoulders, elbows and wrists (a total of eleven elements). The surface area of the retroreflective material that faced the oncoming vehicle was kept constant across conditions in order to isolate the effects of the configuration of the reflective markers on conspicuity.

2.4 Test Vehicle and Measuring System

The test vehicle was an instrumented 1997 Nissan Maxima that had been serviced (including headlamp alignment) immediately prior to the experiment. The windshield was kept clean throughout data collection. Two digital video cameras were mounted a fixed distance apart on the roof of the vehicle. This system recorded two overlapping images of the forward road scene, and was linked to a large (6 cm x 12 cm) luminous dash-mounted touchpad. This system recorded the exact moment that the participant pressed the touchpad to indicate that they saw that a pedestrian was present. Upon a press of the touchpad the relevant video frames were marked for off-line analysis. These images were analyzed to determine the positions of a corresponding point in the marked images. The difference in position of these points (parallax) was used to calculate response distances – the distance separating the vehicle from the pedestrian at the moment that the driver pressed the touchpad. To minimize measurement error, traffic cones with retroreflective markers were positioned strategically along the near shoulder of the roadway. Thus when a driver pressed the touchpad to indicate that a pedestrian was recognized, the measurement system was only required to measure the distance from the test vehicle to the nearest traffic cone. The distance from that cone to the pedestrian was known in advance and was added to the measurement. The speed of travel at the time that the driver pressed the touchpad was also recorded. Two experimenters were always present in the vehicle.

2.5 Procedures

Prior to starting the eleven data collection laps, each participant completed a practice lap. The primary purpose of this lap was to familiarize the driver with the vehicle and the circuit. The secondary purpose of this lap was to measure the drivers' reaction time (described below). All pedestrian recognition data were collected on laps 2-12. At the start of each of these laps the drivers were reminded of their tasks. They were instructed to follow the prescribed route, to drive at a speed that felt comfortable, and to press the touchpad (and to announce "pedestrian!") as soon as they recognized that a pedestrian was present. They were instructed not to press the touchpad until they were confident that what they saw was a pedestrian. They were also informed that there would not always be pedestrians present. To increase driver workload, participants were also instructed to read aloud all road signs that they encountered, although performance on this task was not recorded.

To evaluate the speed with which the drivers could respond to a visible event, reaction times were recorded during the driver's practice lap. This was accomplished by instructing the driver that at some point during this lap a large bright red light would appear on the left or right shoulder of the road and that when they saw this light they should press the touchpad as quickly as possible. The light was a battery powered array of bright red light emitting diodes (LEDs; 11.5 x 19.5 cm) positioned on the near shoulder of the straight section of the road. An experimenter remotely activated the LEDs when both of the vehicle's headlights became visible.

2.6 Experimental Design

The pedestrians' clothing (5 configurations) was manipulated within-subjects. In addition, Pedestrian 1 stood still during half of the laps and walked in place during the other half; he was always surrounded by clutter. Pedestrian 2 always walked in place but was surrounded by clutter on only half of the laps; clutter was manipulated by placing (or removing) black cloth covers over the clutter elements in zone 3. Both pedestrians had received practice in achieving a consistent and natural gait while walking in place. Driver age was the only between-subjects factor. The 10 combinations of clothing and motion for Pedestrian 1 were presented in a different random order for each driver. Similarly, the 10 combinations of clothing and clutter for Pedestrian 2 were presented in a different random order for each driver. The data were collected across eleven data collection laps. Pedestrian 1 was absent during lap 7 and Pedestrian 2 was absent during lap 3. No pedestrians were present during the practice lap.

The percentage of trials in which drivers correctly identified the presence of each pedestrian was recorded. Pedestrian recognition was recorded if the driver pressed the touchpad at any point along the approach to the pedestrian or immediately after having passed the pedestrian. This procedure is liberal in that recognition does not imply that the driver would have been able to initiate a successful avoidance maneuver. For Pedestrian 2, the drivers' response distances were also recorded. Response distance is defined as the distance from the vehicle to the pedestrian at the moment the touchpad was pressed. Response distances were coded as zero for all trials in which the driver did not respond to the test pedestrian or had passed the pedestrian before pressing the touchpad. Because the roadway curvature limited the sight distance of Pedestrian 1, response distances were not measured for this pedestrian.

3. Results

After excluding one unusually long response time ($z = 3.0$) from an older driver who momentarily forgot the reaction time task, the mean reaction times recorded during the practice lap were not significantly different between the younger (M = 1.56 s) and the older (M = 1.53 s) drivers, $t(20) = 0.14$, $p = .89$.

Figures 2a and 2b present the percentage of laps during which the drivers correctly recognized that Pedestrians 1 and 2 were present. Although drivers responded to Pedestrian 1 on 55% of the laps overall, recognition performance varied widely across conditions. For example, recognition never occurred (0% seen) when older drivers approached Pedestrian 1 standing still and wearing either the Black or Vest configurations. But recognition always occurred (100% seen) when drivers from both age groups approached Pedestrian 1 walking in place and wearing either the A+W or the Full Biomotion configurations (and when younger drivers encountered this pedestrian walking while wearing the Ankles configuration). To analyze the separate effects of pedestrian clothing, driver age, and pedestrian motion on the frequency with which drivers responded to Pedestrian 1, logistic regression models were fit to the percent-seen data. The regression indicated that the effect of clothing configuration was significant, $\chi^2(4) = 71.5$, $p < 0.001$. Averaged across driver age and pedestrian motion, Pedestrian 1 was seen on 10%, 15%, 77%, 79%, and 94% of the laps when wearing the Black, Vest, Ankles, A+W, and Full Biomotion configurations, respectively. The effect of driver age was also significant, $\chi^2(1) = 10.8$, $p = 0.001$, indicating that on average the younger drivers (63%) recognized Pedestrian 1 significantly more often than the older drivers (48%). In addition, pedestrian motion significantly affected recognition performance, $\chi^2(1) = 14.8$, $p < .005$, indicating that Pedestrian 1 was recognized significantly more often when he walked in place (64%) than when he stood still (46%).

As can be seen in Figure 2b, drivers responded to Pedestrian 2 on 67% of laps overall, with performance again ranging from 0% seen (older drivers, black clothing, clutter) to 100% seen (in 7 of the 20 conditions, mostly involving the A+W and Full Biomotion configurations). Logistic regression revealed that the effect of clothing configuration was significant, $\chi^2(4) = 63.2$; $p < 0.001$. Averaged across clutter and driver age, Pedestrian 2 was seen on 21%, 31%, 88%, 98%, and 96% of the laps when wearing the Black, Vest, Ankles, A+W, and Full Biomotion configurations, respectively. The effect of driver age was also significant, $\chi^2(1) = 17.5$, $p < 0.001$, indicating that the recognition performance of the older drivers (57% seen) was significantly worse than that of the younger drivers (77% seen). Importantly, the effect of clutter was not significant, $\chi^2(1) = 1.6$, $p = 0.21$, indicating that drivers' ability to recognize the presence of Pedestrian 2 when clutter was present (64%) was not significantly different from when clutter was absent (69%).

Prior to analyzing drivers' response distances for Pedestrian 2, two outlying values (each > 3 standard deviations from their mean) were replaced with the mean of the remaining participants in the relevant condition. Figure 3 presents the drivers' mean response distances to Pedestrian 2 as a function of clothing configuration and clutter. A mixed-model ANOVA tested the separate and combined effects of pedestrian clothing, clutter, and driver age on the response distance data. A significant main effect of pedestrian clothing, $F(4,88) = 100.7$, $p < .001$, $\eta^2 = .82$, confirmed that conspicuity varied dramatically across these clothing configurations. When averaged across the clutter and age variables, mean response distances (and standard deviations) varied from 2.6 m (6.3 m) and 9.1 m (22.6 m) in the Black and Vest conditions, respectively, to 139.3 m (114.1 m), 212.7 m (117.7 m), and 181.0 m (103.7 m) in the Ankles, A+W, and Biomotion conditions, respectively. Bonferroni follow-up tests revealed that all pairwise comparisons were significant ($p < .05$) with three exceptions – Black/Vest, Ankles/Full Biomotion, and A+W/Full Biomotion. There was also a significant main effect of driver age, $F(1,22) = 34.7$, $p < .001$, $\eta^2 = .61$, indicating that the mean response distance of the younger drivers, 152.9 m (std. dev. = 143.3 m), was significantly (and 2.35 times) greater than the mean of the older drivers, 65.0 m (std. dev. = 77.5 m). Importantly, the main effect of clutter was not significant, $F(1,22) = 1.94$, $p = .18$, $\eta^2 = .08$, thus the mean response distance when clutter was present, 104.2 m (std. dev. = 121.0 m), was not reliably different from the mean without clutter, 113.6 m (std. dev. = 125.6 m). Neither the interaction between clutter and clothing, $F(4,88) = 0.83$, $p = .44$, $\eta^2 = .04$, nor the interaction between clutter and age, $F(1,22) = 0.04$, $p = .84$, $\eta^2 = .002$, reached significance. In fact, the only significant interaction was between clothing and driver age, $F(4,88) = 12.8$, $p < .001$, $\eta^2 = .37$; see Figure 4. Here, the simple effect of clothing was significant for both age groups but was somewhat larger for the younger drivers, $F(4,44) = 67.0$, $p < .001$, $\eta^2 = .86$, than for the older drivers, $F(4,44) = 34.7$, $p < .001$, $\eta^2 = .76$. To explore this interaction further, the mean response distances for each clothing configuration were compared across the two age groups. These analyses revealed that the mean response distance of the younger drivers was significantly greater than that of the older drivers at each of the 5 clothing configurations, but this age effect was smaller in the Black and Vest conditions than in the Ankles, A+W, and Full Biomotion configurations.

4. Discussion

Previous researchers have quantified the difficulty that drivers have in seeing pedestrians at night, and reflective vests are commonly used in an attempt to enhance pedestrians' conspicuity. But research has repeatedly demonstrated that pedestrians are even more conspicuous to drivers at night when reflective material is attached to the pedestrian's major moveable joints rather than to their torso (Balk, et al., 2008; Blomberg, et al., 1986; Luoma & Penttinen, 1998; Luoma, et al., 1996; Owens, et al., 1994; Owens, et al., 2007; Sayer & Mefford, 2004; Wood, et al., 2005). The conspicuity benefit associated with these limb markings has been attributed to our perceptual sensitivity to the distinctive patterns of "biological motion" that are associated with normal human gait. However, in contrast to the widely reported conspicuity benefits that biological motion configurations provide, one previous study failed to find a conspicuity advantage associated with biological motion (Moberly & Langham, 2002). Those authors suggested that biological motion configurations may not be effective when the pedestrian is surrounded by visual clutter. The present study addressed this issue explicitly. Three patterns in the present data confirm that clothing configurations that include reflective markings on the limbs offer conspicuity advantages that are both significant and substantial, even in the presence of visual clutter.

First, drivers responded to Pedestrian 2 significantly more often, and at significantly greater distances, when the pedestrian wore clothing configurations that incorporated reflective markings on his extremities (i.e., the Ankles, A+W, and Full Biomotion configurations) than when he wore the same amount of reflective material on his torso. Averaged across the clutter manipulation, drivers responded to Pedestrian 2 on only 31% of trials when he wore the vest. The same drivers responded to the same pedestrian more frequently when he wore the Ankles (88% seen), A+W (98% seen), or Full Biomotion (96% seen) configurations. And the mean response distance from the Vest condition (9.1 m) is far short of the mean response distances from the Ankles (139.3 m), A+W (212.7 m), and Full Biomotion (181.0 m) configurations. Indeed, the mean response distances from the Vest and Black conditions were not significantly different. Thus the retroreflective vest did not significantly enhance conspicuity; it was only when the reflective material was mounted on the extremities that it provided a substantial conspicuity benefit.

Second, the addition of visual clutter surrounding Pedestrian 2 did not significantly affect drivers' performance. Neither the frequency with which drivers responded to this pedestrian nor the distance at which the drivers responded were significantly altered by the addition of clutter. While there was a small trend in the direction of clutter reducing both the percentage of trials in which the driver responded (69% seen without clutter, 64% seen with clutter), and the mean distance at which they responded (113.6 m without clutter, 104.2 m with clutter), these effects were neither statistically significant nor large enough to explain the lack of a biomotion advantage reported by Moberly and Langham (2002). Further, the clutter manipulation did not interact significantly with either pedestrian clothing or driver age, indicating that the effect of clutter was uniformly weak across these other variables. Contrary to the suggestion by Moberly and Langham (2002) that visual clutter may compromise the perceptual value of biological motion information, clutter did not degrade drivers' performance in the full biomotion configuration any more or less than in other configurations.

Third, the significant effect of pedestrian motion on the frequency with which drivers responded to Pedestrian 1 are also consistent with the hypothesis that biomotion enhances conspicuity. On average, drivers responded to Pedestrian 1 on 64% of trials when this pedestrian was walking but on only 46% when the he stood still. Importantly, however, the performance benefits associated with the addition of pedestrian motion depended on the clothing configuration (see Figure 2a). Adding pedestrian motion to the Vest configuration increased recognition performance only from 13% to 17%. But when pedestrian motion was added to the Ankles configuration recognition performance jumped from 58% to 96%. And 100% of drivers responded when Pedestrian 1 was walking while wearing the A&W and Full Biomotion configurations (the corresponding means for these configurations when the pedestrian was stationary were 58% and 88%, respectively). Thus it seems clear that even in the presence of visual clutter, pedestrian motion is most beneficial when the pedestrian's extremities are highlighted with reflective markings. Interestingly, when Pedestrian 1 stood still recognition performance was still highest in the Full Biomotion configuration. This indicates that motion-based perceptual mechanisms are not entirely responsible for the biological "motion" effect; form perception mechanisms that facilitate the perception of the static human form also appear to be involved. This effect, which further indicates the robustness of limb markings, was also reported by Balk, et al. (2008).

In sum, it appears that even in the presence of visual clutter pedestrians are substantially more conspicuous when they wear retroreflective markings in a configuration that facilitates drivers' perception of biological motion. This conclusion is consistent with the majority of other relevant studies (Balk, et al., 2008; Blomberg, et al., 1986; Luoma & Penttinen, 1998; Luoma, et al., 1996; Owens, et al., 1994; Owens, et al., 2007; Sayer & Mefford, 2004; Wood, et al., 2005), but the finding stands in contrast to the results of Moberly and Langham's (2002) study. While it remains unclear why that study did not find a biomotion advantage, one possible explanation is that participants in that study sat in a laboratory and watched a video depiction of a night-driving scenario. The technical limitations associated with accurately depicting the visual characteristics of nighttime scenarios, as well as the reduced demands associated with watching a video as opposed to actually driving a vehicle at night, are likely to be relevant. Consistent with this possibility is the fact that in the study by Owens, et al. (1994) that also involved asking participants to respond to pedestrians in videotaped night driving scenarios the benefit of biomotion appeared to be greater when the participants were engaged in a secondary task (steering a simulated vehicle) than when their only task was to respond to the videotape.

Another way in which the Moberly and Langham methods differed from other relevant studies is that in their videos the pedestrian faced the roadway, thus giving the participants a side-on view of the pedestrian. Balk, et al. (2007) recently presented evidence that biological motion configurations are more effective when viewed from the pedestrian's front than when they are viewed from the side. In that study, passengers who were driven past a pedestrian who either stood still or walked in place on the far shoulder of the roadway responded to the pedestrian from a mean distance of 87.2 m when the pedestrian faced the approaching vehicle but from only 52.7 m when the pedestrian was oriented such that his right side faced the oncoming vehicle. This effect of pedestrian orientation was particularly large when the pedestrian wore a full biological motion configuration or an ankles and wrists configuration, and was not significant when the pedestrian wore an ANSI class II reflective vest. A smaller biomotion advantage when in side-on view may have resulted from key elements of the configuration (especially the distant limbs) being blocked from view by the pedestrian's body; the remaining markers may produce a motion pattern that is less perceptually salient. The possibility that the effectiveness of clothing-based approaches to enhancing pedestrian conspicuity can vary as a function of pedestrian orientation is worthy of future study.

A reviewer commented that the discrepancy between the results of the present study and Moberly and Langham's study might be a result of differences in the configurations of the two vests. Whereas the vest used by Moberly and Langham (2002) consisted of two horizontal stripes we used a single rectangular configuration. Given the findings of Balk, et al. (2007), however, it seems unlikely that differences in vest configurations can account for the discrepant findings. In the Balk, et al. (2007) study, a walking pedestrian was consistently more conspicuous when wearing a biomotion configuration than when wearing a vest that featured the ANSI class II configuration (a U-shaped configuration of retroreflective material). Thus while it is possible that different vest configurations can result in differing degrees of conspicuity, the bulk of the evidence supports the conclusion that placing retroreflective markings on pedestrians' extremities is more effective than marking the torso.

Also, while Moberly and Langham (2002) argued that "high visual clutter" might explain the lack of a biomotion advantage, they did not manipulate the amount of visual clutter that was present in their videotaped scenarios. Their claim seems less tenable given the results of the present study since the clutter in present study was likely greater, not unlike a pedestrian in the midst of a construction site. Moberly and Langham did not provide a detailed description of the clutter that was present in their roadway environment, but it appears to have all been naturally occurring items, at least some of which were retroreflective.

It seems safe to assume that until clothing that incorporates retroreflectors in biological motion configurations becomes widely available, only the most motivated and safety-conscious pedestrians are likely to add the full complement of biomotion retroreflectors to their own clothing. The Ankles and A+W configurations were included in the present study to explore the conspicuity value of configurations that are more convenient for pedestrians. The Ankles and A+W configurations are convenient subsets of the full configuration and have the advantage of visually highlighting the parts of the body that are most likely to make salient movements (Ahlström, et al., 1997; Mather, et al., 1992). The fact that pedestrians' ankles are maximally illuminated by low beam headlamps is also a consideration. The data from these configurations are encouraging. Summing across the age and clutter manipulations, neither the Ankles configuration (139.3 m) nor the Ankles and Wrists configuration (212.7 m) resulted in mean response distances that were significantly different from the Full Biomotion configuration (181.0 m). Both of these configurations resulted in response distances that were far greater than the Black (2.6 m) and Vest (9.1 m) conditions, a pattern that was also reported by Balk, et al. (2008). While this suggests that the two "convenient subset" configurations can substantially enhance conspicuity, it must be remembered that (a) to control the reflective surface area across conditions, the ankle and wrist markings in the present study were unusually wide, and (b) the

Ankles and A+W configurations are less effective when the pedestrian is standing still (see Figure 2a).

Because reflective markings that convey biological motion can provide a cheap and effective method of increasing the distance at which approaching drivers can recognize pedestrians, the question of how to persuade pedestrians to wear more conspicuous markings becomes critical. One obstacle to widespread adoption by pedestrians is that typical pedestrians may not recognize the need to increase their nighttime visibility in general or the perceptual value of biomotion markings in particular. In fact, several researchers have found that pedestrians overestimate their own visibility to drivers at night (Allen, Hazlett, Tacker, & Graham, 1970; Shinar, 1984; Tyrrell, Wood, & Carberry, 2004). Further, Tyrrell, et al. (2004) found that the conditions that minimize drivers' ability to see pedestrians (low beams, black clothing) also result in pedestrians maximally overestimating their own visibility. Pedestrians wearing black clothing in that study estimated that drivers would respond to them at a distance that was 7.0 times greater than the distance at which drivers actually responded. It would seem difficult to convince pedestrians to use an intervention (biomotion markings) in order to reduce a problem that they do not believe exists. Two obvious options are to somehow force pedestrians to use biomotion markings or to educate pedestrians about the visibility problem and the value of biomotion markings. The first option may only be practical in contexts in which "professional pedestrians" (e.g., roadway workers, emergency responders, traffic control officers) are at risk. The second option is supported by evidence that an educational approach can successfully reduce pedestrians' overestimates of their own visibility (Tyrrell, Patton, & Brooks, 2004). While this may be a first step towards encouraging pedestrians to enhance their own safety, additional research is clearly needed.

The older drivers in the present study were consistently worse than the younger drivers at responding to pedestrians. Summing across the two pedestrians, the older drivers responded to 52% of the pedestrians while the younger drivers responded to 70%. And the older drivers responded to Pedestrian 2 at a mean distance (65.0 m) that was less than half of mean from their younger counterparts (152.9 m). These results underscore other researchers' findings that the ability to see pedestrians at night declines with age (Luoma & Penttinen, 1996; Luoma & Penttinen, 1998; Sayer & Mefford, 2004; Wood, et al., 2005). Because there was not a significant age difference in the reaction times that were measured during the practice lap it appears that the decreased performance for older drivers is the result of age-related visual changes (see Shinar & Schieber, 1991). Hence, older drivers are even more likely than younger drivers to encounter pedestrians at night who will not be seen from a safe distance.

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References

Ahlström, V., Blake, R., & Ahlström, U. (1997). Perception of biological motion. *Perception*, *26*, 1539-1548.

Allen, M.J., Hazlett, R.D., Tacker, H.L., & Graham, B.V. (1970). Actual pedestrian visibility and the pedestrian's estimate of his own visibility. *American Journal of Optometry and Archives of American Academy of Optometry*, *47*, 44-49.

Balk, S. A., Graving, J. S., Chanko, R. G., & Tyrrell, R. A. (2007). Effects of retroreflector placement on the nighttime conspicuity of pedestrians: An open-road study. *Human Factors and Ergonomics Society Annual Meeting Proceedings*, *51*, 1565-1568.

Balk, S. A., Tyrrell, R. A., Brooks, J. O., & Carpenter, T. L. (2008). Highlighting human form and motion information enhances the conspicuity of pedestrians at night. *Perception*, *37*, 1276-1284.

Blake, R., & Shiffrar, M. (2007). Perception of human motion. *Annual Review of Psychology, 58*, 47-73.

Blomberg, R. D., Hale, A., & Preusser, D. F. (1986). Experimental evaluation of alternative conspicuity-enhancement techniques for pedestrians and bicyclists. *Journal of Safety Research, 17*, 1-12.

Cutting, J. E., & Kozlowski, L. T. (1977). Recognizing friends by their walk: Gait perception without familiarity cues. *Bulletin of the Psychonomic Society, 9*, 353-356.

Grossman, E. D., Battelli, L., & Pascual-Leone, A. (2005). Repetitive TMS over posterior STS disrupts perception of biological motion. *Vision Research, 45*, 2847.

Grossman, E., Donnelly, M., Price, R., Pickens, D., Morgan, V., Neighbor, G., & Blake, R. (2000). Brain areas involved in perception of biological motion. *Journal of Cognitive Neuroscience*, *12*, 711-720.

Johansson, G. (1973). Visual perception of biological motion and a model for its analysis. *Perception & Psychophysics, 14*, 201-211.

Johansson, G. (1975). Visual motion perception. *Scientific American*, *232*, 78-89.

Kwan, I., & Mapstone, J. (2006). Interventions for increasing pedestrian and cyclist visibility for the prevention of death and injuries. *Cochrane Database of Systematic Reviews*, *4*, No. CD003438.

Luoma, J., & Penttinen, M. (1998). Effects of experience with retroreflectors on recognition of nighttime pedestrians: Comparison of driver performance in Finland and Michigan. *Transportation Research Part F: Traffic Psychology and Behaviour, 1*, 47-58.

Luoma, J., Schumann, J., & Traube, E. C. (1996). Effects of retroreflector positioning on nighttime recognition of pedestrians. *Accident Analysis and Prevention, 28*, 377-383.

Mather, G., Radford, K., & West, S. (1992). Low-level visual processing of biological motion. *Proceedings of the Royal Society B: Biological Sciences*, *249*, 149-155.

Moberly, N. J., & Langham, M. P. (2002). Pedestrian conspicuity at night: Failure to observe a biological motion advantage in a high-clutter environment. *Applied Cognitive Psychology, 16*, 477-485.

NHTSA (2008). *Traffic Safety Facts 2006 Data*. Washington, D.C.: National Highway and Traffic Safety Administration's National Center for Statistics and Analysis (available: www.nhtsa.gov).

Owens, D. A., Antonoff, R. J., & Francis, E. L. (1994). Biological motion and nighttime pedestrian conspicuity. *Human Factors, 36*, 718-732.

Owens, D. A., & Sivak, M. (1996). Differentiation of visibility and alcohol as contributors to twilight road fatalities. *Human Factors, 38*, 680-689.

Owens, D. A., Wood, J. M., & Owens, J. M. (2007). Effects of age and illumination on night driving: A road test. *Human Factors*, *49*, 1115-1131.

Pollick, F., Lestou, V., & Ryu, J. (2002). Estimating the efficiency of recognizing gender and affect from biological motion. *Vision Research*, *42*, 2345-2355.

Runeson, S., & Frykolm, G. (1981). Visual perception of lifted weights. *Journal of Experimental Psychology: Human Perception & Performance*, *7*, 733-740.

Runeson, S., & Frykolm, G. (1983). Kinematic specifications of dynamics as an informational basis for person-and-action perception: Expectation, gender-recognition, and deceptive intention. *Journal of Experimental Psychology: General*, *112*, 585-615.

Rumar, K. (1990). The basic driver error: Late detection. *Ergonomics, 33*, 1281-1290.

Rumar, K. (2001). *A worldwide perspective on future automobile lighting*. (No. UMTRI-2001-35). University of Michigan Transportation Research Institute.

Sayer, J. R., & Mefford, M. L. (2004). High visibility safety apparel and nighttime conspicuity of pedestrians in work zones. *Journal of Safety Research, 35*, 537-546.

Shinar, D. (1984). Actual versus estimated night-time pedestrian visibility. *Ergonomics*, *27*, 863-871.

Shinar, D., & Schieber, F. (1991). Visual requirements for safety and mobility of older drivers. *Human Factors, 33*, 507-519.

Sivak, M., Luoma, J., Flannagan, M. J., Bingham, C. R., Eby, D. W., & Shope, J. T. (2007). Traffic safety in the U.S.: Re-examining major opportunities. *Journal of Safety Research, 38*, 337-355.

Sullivan, J. M., & Flannagan, M. J. (2002). The role of ambient light level in fatal crashes: Inferences from daylight saving time transitions. *Accident Analysis and Prevention, 34*, 487-498.

Tyrrell, R.A., Patton, C.W., & Brooks, J.O. (2004). Educational interventions successfully reduce pedestrians' overestimates of their own nighttime visibility. *Human Factors*, *46*, 170-182.

Tyrrell, R.A., Wood, J.W., & Carberry, T.P. (2004). On-road measures of pedestrians' estimates of their own nighttime conspicuity. *Journal of Safety Research*, *35*, 483-490.

Wood, J. M., Tyrrell, R. A., & Carberry, T. P. (2005). Limitations in drivers' ability to recognize pedestrians at night. *Human Factors, 47*, 644-653.

Figure Captions

Figure 1. Map of the closed road, including the positions of the 2 pedestrians and the 3 clutter zones. Arrows indicate the test vehicle's direction of travel.

Figure 2. The percentage of laps during which the driver correctly pressed the touchpad to indicate that Pedestrian 1 (Figure 2a) and Pedestrian 2 (Figure 2b) was present. Responses are presented as a function of clothing configuration and pedestrian motion (Figure 2a) and clothing configuration and whether visual clutter surrounded the pedestrian (Figure 2b).

Figure 3. The mean (plus 1 standard error) distance at which drivers responded to Pedestrian 2 as a function of clothing configuration and clutter.

Figure 4. The mean (plus 1 standard error) distance at which drivers responded to Pedestrian 2 as a function of clothing configuration and driver age.

Figure(s)

Figure 1

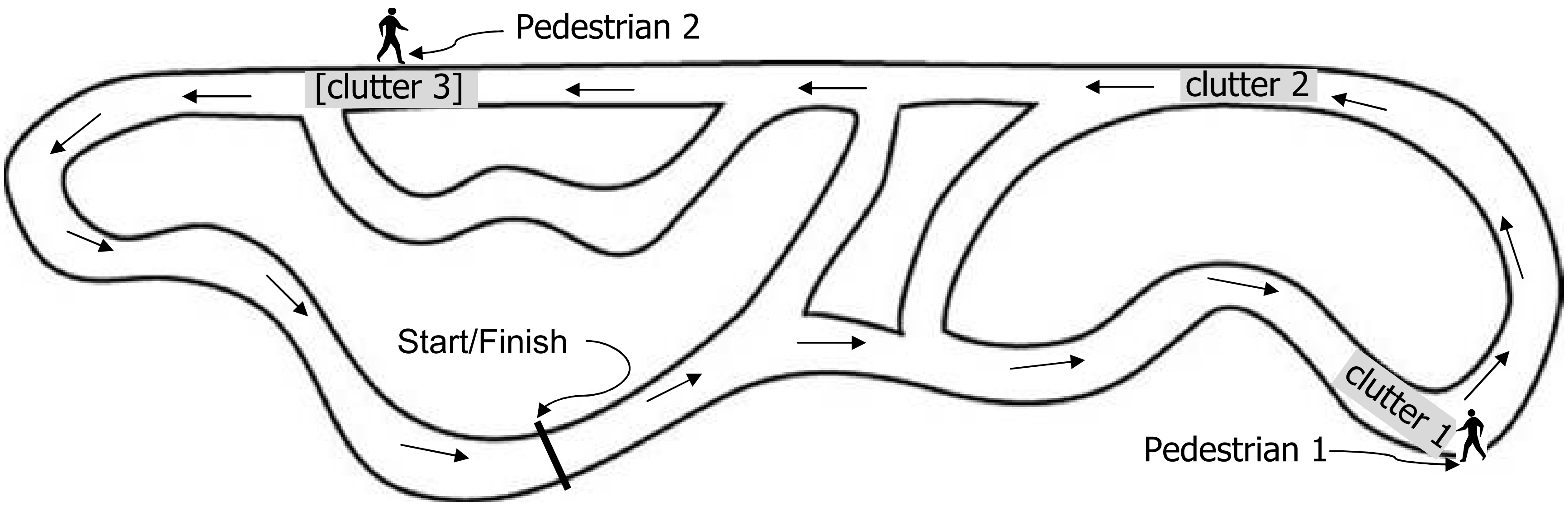
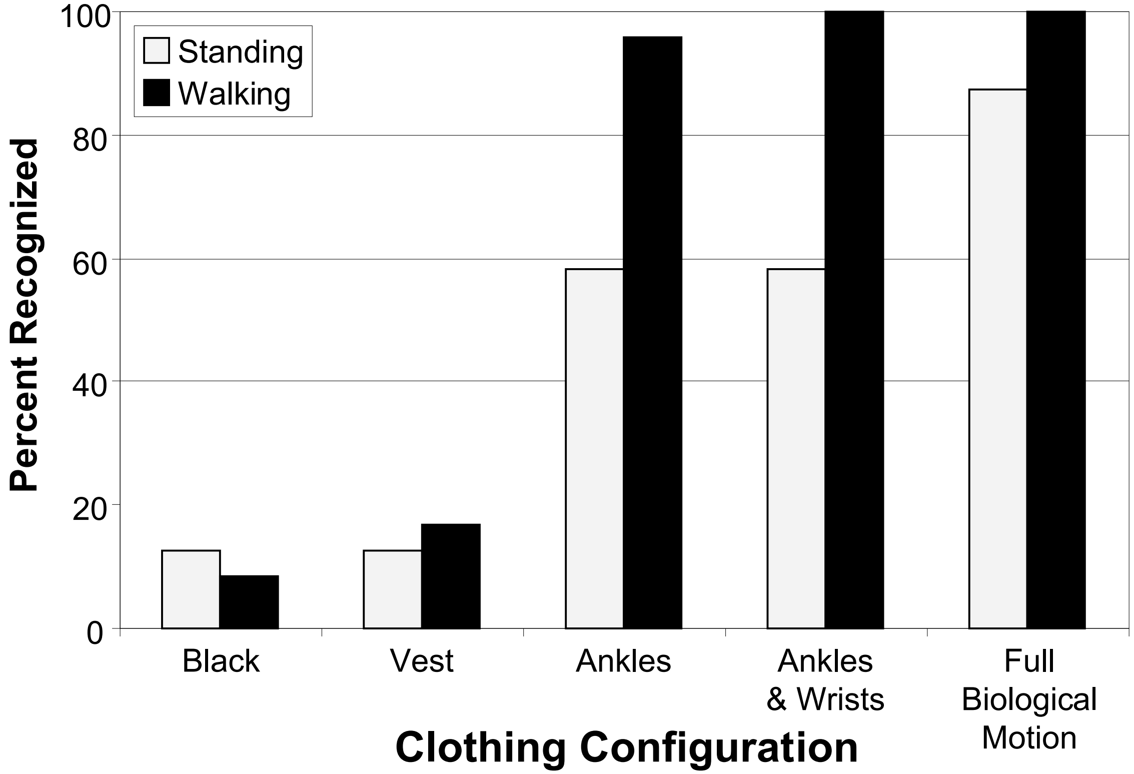
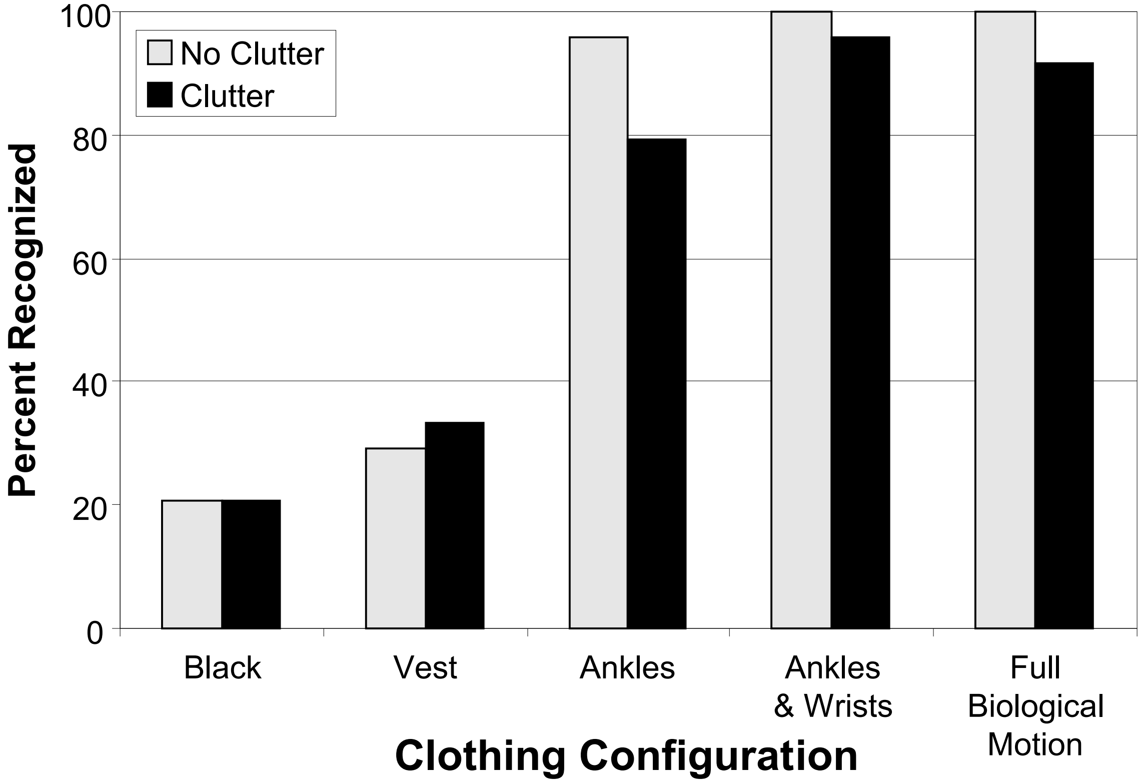


Figure 2a



100
80
60
40
20
0
Percent Recognized
Standing
Walking
Black
Vest
Ankles
Ankles & Wrists
Full Biological Motion
Clothing Configuration

Figure 2b



No Clutter
Clutter
Percent Recognized
100
80
60
40
20
0
Black
Vest
Ankles
Ankles & Wrists
Full Biological Motion
Clothing Configuration

Figure 3

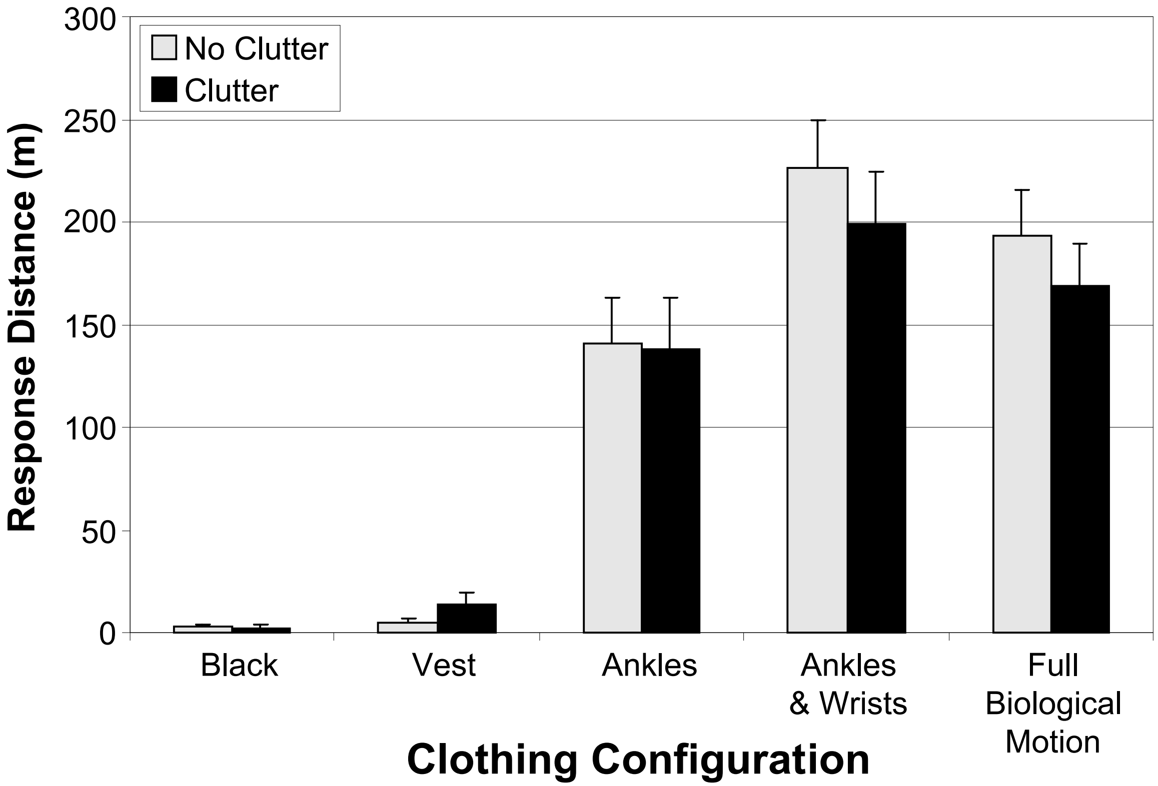
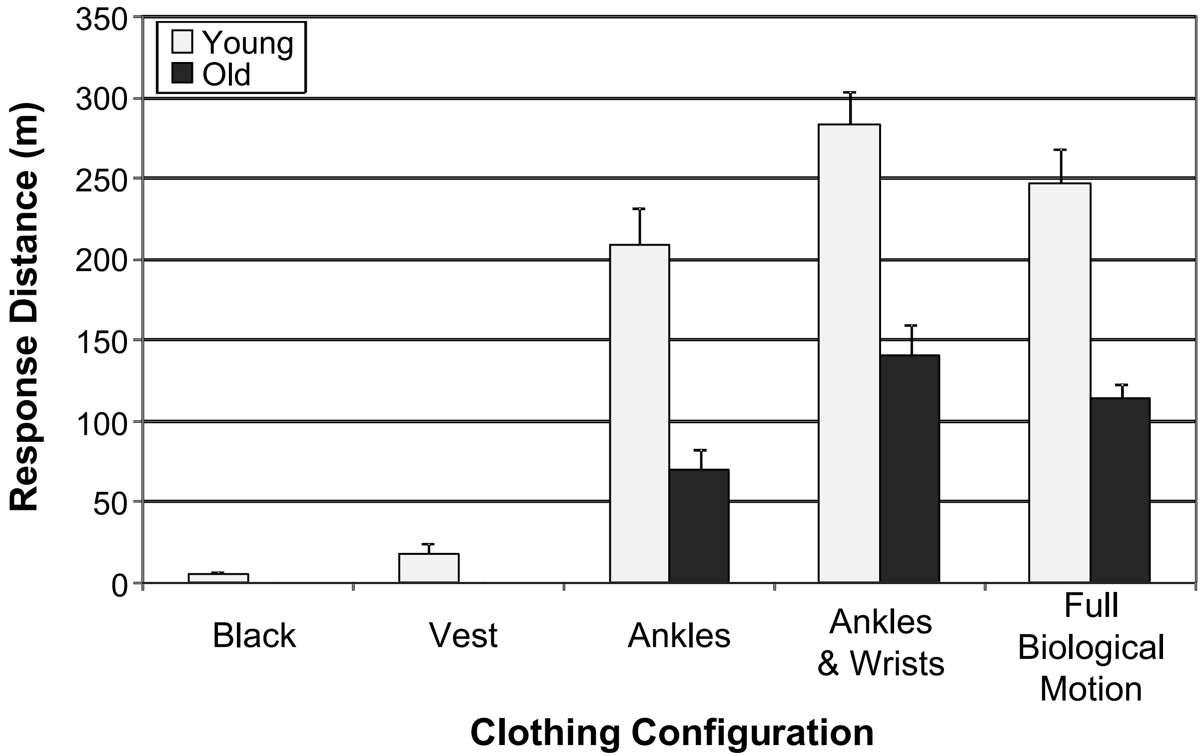

300
250
200
150
100
50
0
Response Distance (m)
No Clutter
Clutter
Black
Vest
Ankles
Ankles & Wrists
Full Biological Motion
Clothing Configuration

Figure 4


350
300
250
200
150
100
50
0
Young
Old
Response Distance (m)
Black
Vest
Ankles
Ankles
& Wrists
Full
Biological
Motion
Clothing Configuration